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NOTE ON SULFITE WASTE LIQUOR AND DISSOLVED OXYGEN CONCENTRATIONS IN THE VICINITY OF A SUBMARINE OUTFALL

by

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ABSTRACT

Monthly oceanographic surveys have been conducted in the vicinity of Everett, Washington since May 1962. One purpose of these surveys, which still continue, is to determine the distribution of sulfite waste liquor emanating from a deep submarine diffuser outfall serving two pulp mills.

Examples of summer and winter sulfite waste liquor and dissolved oxygen conditions in Possession Sound are given. Concentrations of sulfite waste liquor greater than 5 mg/l are found at depth at distances greater than 10 km from the diffuser. Oxygen demand of mill waste products is traceable at depth to 8 km from the source. The diffuser itself approximates a continuous point source.

INTRODUCTION

Since May 1962, the U. S. Public Health Service and Washington Pollution Control Commission have been engaged in joint investigations of the waters in the vicinity of Everett, Washington. One aspect of this work is presented here--namely, the distribution of sulfite waste liquor (SWL) discharged via a submarine diffuser line and the effect of SWL on local oxygen resources.

STUDY AREA

Everett is situated on Port Gardner which is part of the Puget Sound system (Figures 1 and 2). Tides in Puget Sound are mixed, and the mean diurnal range is 3.4 meters. Tidal currents are not well known at present but are described by the U. S. Coast & Geodetic Survey (1952) as "weak and variable".

Net motion is northward along the bottom. Considerable dilution of surface waters occurs due to precipitation, runoff from the Snohomish River, and advection of dilute surface waters. Sills of relatively shallow depth are situated at the entrances to Port Susan. The effect of these sills on water exchange in Port Susan and on oxygen consumption therein has been described by Barnes and Collias (1958).

Numerous hydrographic stations have been occupied in Possession Sound and adjacent areas by the University of Washington since 1952. Time-series analysis of their data indicates that the bottom water in Possession Sound is renewed via water entering the Strait of Juan de Fuca. There is a lag of approximately six weeks from the time deep water passes Race Rocks until it enters Possession Sound.

WASTE EFFLUENT

There are two large sulfite pulp mills situated in Everett. Waste waters from these mills are discharged into the surface waters of the inner harbor and through a submerged outfall. The surface discharge results primarily from log barking processes used prior to reducing the logs, white waters from pulp and paper machines, and bleach plant effluents. The waste liquor from the two mills is transported to a surge tank by a single pipeline. The liquor is then discharged at depth from the surge tank.

The submerged pipeline is 914 meters long, of which the last 305 meters consist of a multiple-port diffuser line. The upper part of the diffuser lies in about 50 meters of water, and the lower part in about 100 meters.

According to pulp mill data, total discharge to the submerged outfall is approximately 79.5 x 10^3 cubic meters per day and is continuously discharged throughout a day. Included in this volume of water, 1,277 metric tons of dissolved solids and 4.58 metric tons of fiber are discharged. Biochemical oxygen demand is estimated at 386.4 metric tons per day.

METHODS

At approximately one-month intervals, hydrographic stations were occupied at about one nautical-mile intervals radially from the end of the pipeline (Figure 2). Water samples are collected using teflon-coated Nansen bottles, usually at depths of 0, 5, 10, 20, 30, 50, 75, 100, 125, and 150 meters, depth permitting.

Sulfite waste liquor concentration is determined by the Barnes et al. (1963) modification of the Pearl-Benson (1940) technique. This is a measure of the lignin content of water originating from the pulping processes employed by the pulp mills. The test does not give an indication of spent chemicals, sugars, and other componenets, that are also included under the term sulfite waste liquor (or, as some prefer, spent sulfite liquor). Concentrations of SWL of 5 mg/l or less are generally considered "background". Other substances, such as pea vine wastes or sanitary sewage, will give significant SWL values. In the region considered concentrations of greater than 5 mg/l SWL are due solely to the presence of lignin. Measurable oxygen demand is by substances other than lignin (hexoses, pentoses) but good correlation exists between SWL concentration and oxygen deficiency.

In addition to SWL; temperature, salinity, dissolved oxygen, and pH are routinely measured from the same Nansen bottle from which the SWL sample was obtained. Dissolved oxygen is determined by the Alsterberg (azide) modification (APHA, 1960) of the Winkler test. The Rennerfelt (1955) test of the effect of SWL on the azide determination of dissolved oxygen showed no lowering of dissolved oxygen at the SWL concentrations encountered. (Dissolved oxygen in the presence of SWL will be determined in the field by gas chromatography and in situ by galvanic cell analyzer in the summer of 1963.)

RESULTS

Station positions shown in Figure 2 were occupied on August 2-3, 1962. Tidal conditions are indicated in the inset. A vertical section of SWL concentration along the line connecting hydrographic stations in Figure 2 is given in Figure 3. This section extends from the pipeline into Saratoga Passage. About six hours were required to occupy the stations. There is a pronounced tongue of high (50 mg/l) SWL concentration extending 4 km from the diffuser at about 75 meters depth. The tongue gradually rises to about 40 meters where the concentration diminishes to 22 ppm at 8 km. The figure also shows a secondary tongue of SWL at about 20 meters (SWL conc. 400 mg/l). ~~which is believed to be due to a break in the line at shallow depth.~~ The surface waters show concentrations of 10-20 ppm. Thermocline depth during this cruise was 5-10 meters, and the depth of the halocline was 2-5 meters.

Figure 4 shows oxygen distribution along the same section during the August cruise. Plume depths and configurations of low dissolved oxygen and high SWL concentration are similar.

A horizontal section of SWL at 75 meters during this cruise is shown in Figure 5. The tongue extending into Possession Sound is pushed north of the pipeline due to tidal currents acting at the time of this cruise. The position of the isopleths of SWL indicates that the net current is into Saratoga Passage with little tidal mixing east of Mukilteo.

A vertical section of SWL along the same line is shown for a cruise of January 31-February 1, 1963, in Figure 6. The depth of the plume here is considerably shallower than that of the August cruise, particularly at stations distant from the diffuser. Halocline depth was 5-7 meters; there was a positive temperature gradient, i.e., temperature increased with depth.

Figure 7 is a profile of dissolved oxygen on the late January cruise. Concentrations of SWL are less than those in the August cruise (Figure 6), and consequently, oxygen demand is also less.

The average values of ten sections occupied from May 1962 to April 1963 is given in profile in Figure 8. Here the plume depth at the pipeline is about 75 meters, decreasing to 50 meters with distance from the pipeline. The depth of maximum concentration is also shown. These data can be more clearly exhibited on a semi-logarithmic plot as in Figure 9. Here the ratio Cx/Co is the ordinate and distance from the pipeline is the abscissa. Co is maximum SWL concentration at depth near the pipeline, and Cx the value at distance from it. Figure 9 exhibits averaged values of SWL over the pipeline. Values were taken at the axis of the plume core, shown in Figure 8.

SWL concentration in the immediate vicinity of the pipeline is extremely variable. If the station is occupied a few hundred meters north or south of the pipeline, concentrations can be orders of magnitude less than that immediately over the pipeline. In order to eliminate this bias, a similar plot was made using values at 0.9 km from the end of the pipeline (Figure 9-B). It can be seen that the slopes of the lines are similar in this particular case. Figure 9 indicates that there is fairly rapid decrease in SWL concentration for a distance of about 1.6 - 1.9 km from the end of the line. There is a decrease in dilution at the distances greater than this, but the decrease is also exponential. Specific values of dilution with reference to initial values (Co) are obtained as $(Cx/Co)^{-1}$.

DISCUSSION

The two pulp mills in the Everett area operate on a round-the-clock basis, seven days a week. Although effluent from the surge tank to the pipeline is not monitored as to volume of flow, plant records indicate the flow is continuous except, of course, during periods when the mills are closed down for repairs or holidays.

Ideally, a point source is just that--a small opening through which a substance is introduced into bodies of various dimensions and densities. The mathematical solutions for many problems involving vertical and horizontal diffusion from point and line sources (see Carslaw and Jaeger, 1959) exist for instantaneous (see Okubo, 1962) and continuous discharges. As a first approximation, the diffuser section of the submarine outfall may be thought of as a point source, continuous discharge.

No information has yet been obtained on the magnitude of diurnal fluctuations of velocity, density, or SWL with depth, hence it is premature to attempt to apply existing theory to the prediction of SWL dispersion in the Everett area. To further complicate the issue, Westley (1960) finds from experiments in an enclosed lagoon that SWL is not a conservative substance. He found that SWL (as measured by the Pearl-Benson technique) had a half-life of about five days at 20°C and 9.5 days at 11.7°C. His experiments were conducted in semi-field conditions in a shallow lagoon with maximum depth of 4 meters. No estimates of boundary absorption or the degree of mixing were given.

SUMMARY

The field work to date has been of a general survey nature in which long term trends in salinity, dissolved oxygen, and SWL concentrations have been followed. This work has provided the needed background for small scale (in time and space) investigations in which diurnal and short term effects may be studied. Certain empirical relations, such as that shown in Figure 9, have provided first order estimates of zones of initial, rapid dispersion and dilution of SWL. The limits of SWL distribution have been mapped for various tidal and climatic conditions.

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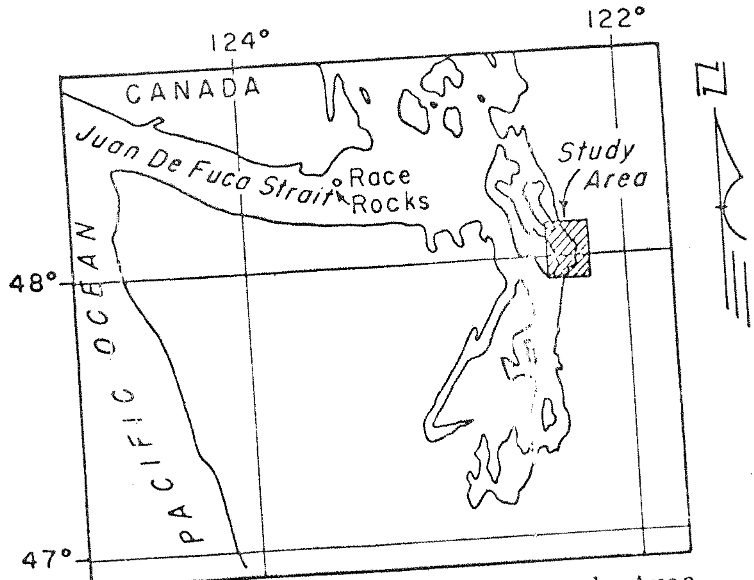

FIGURE 1. Puget Sound and Study Area

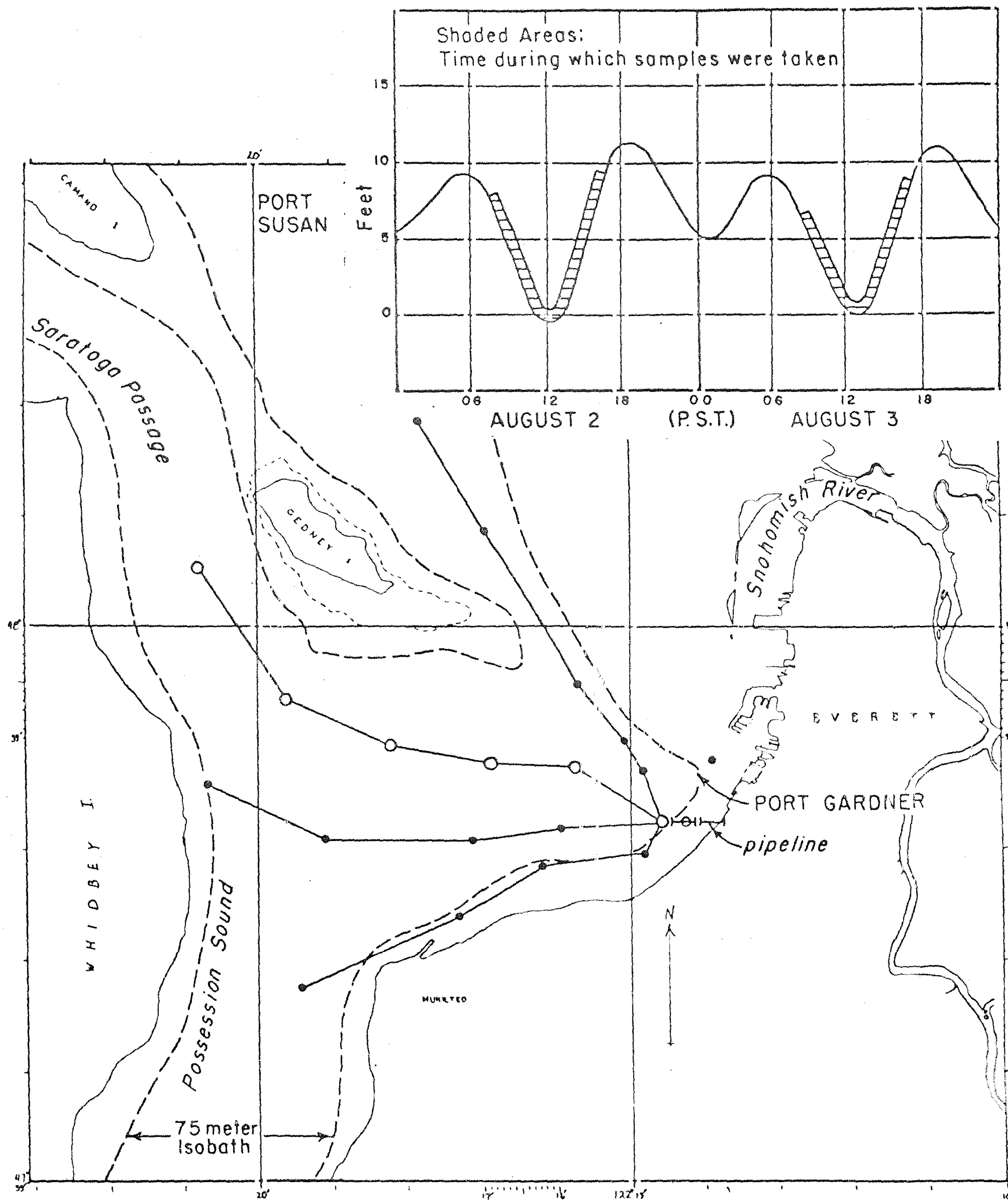

FIGURE 2. Station locations, August 1962. Open circles show stations used in vertical sections.

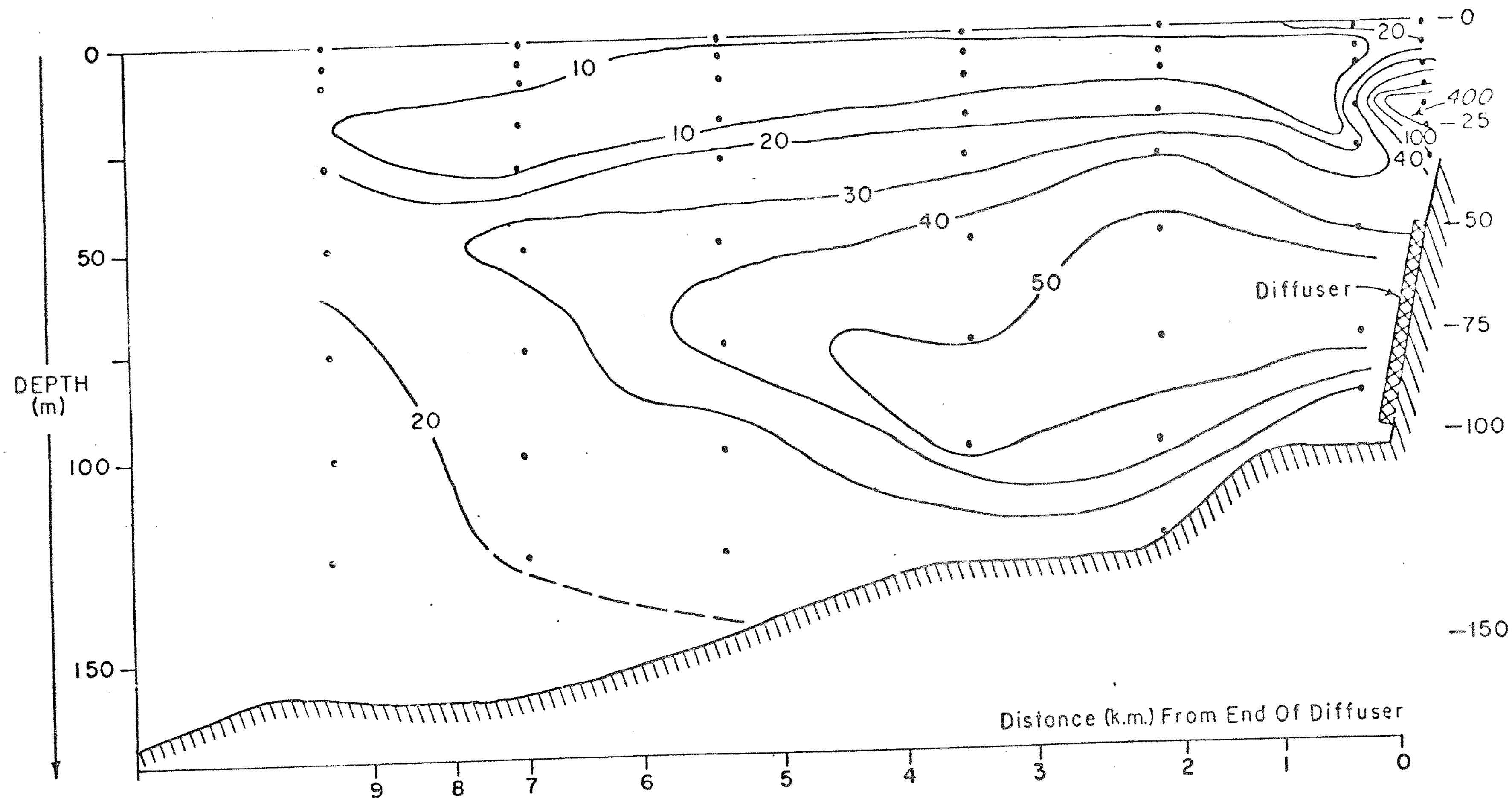

FIGURE 3. Vertical section of SWL (mg/1), August 1962. Pipeline to Saratoga Passage.

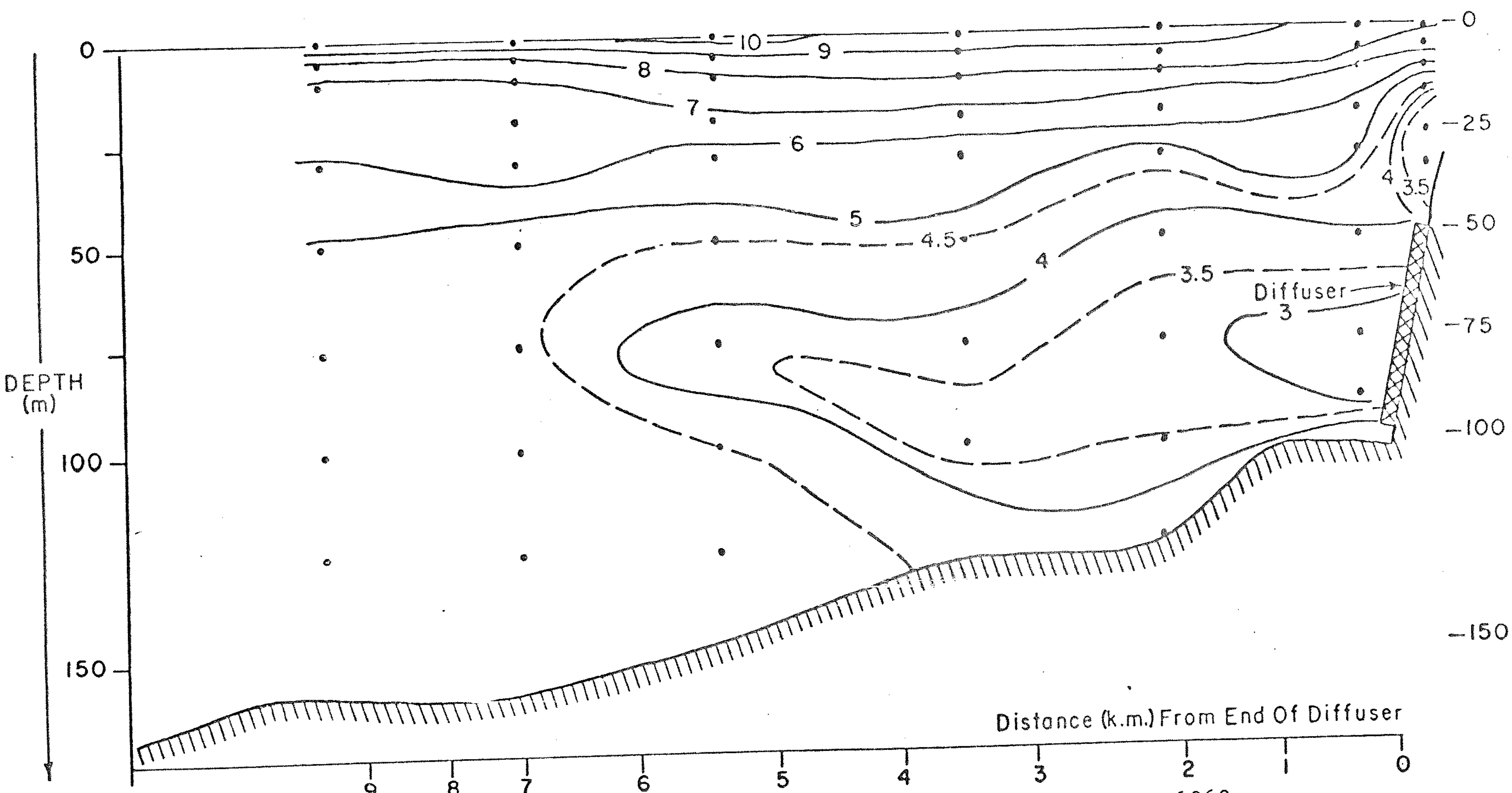

FIGURE 4. Vertical section of dissolved oxygen (mg/1), August 1962. Pipeline to Saratoga Passage.

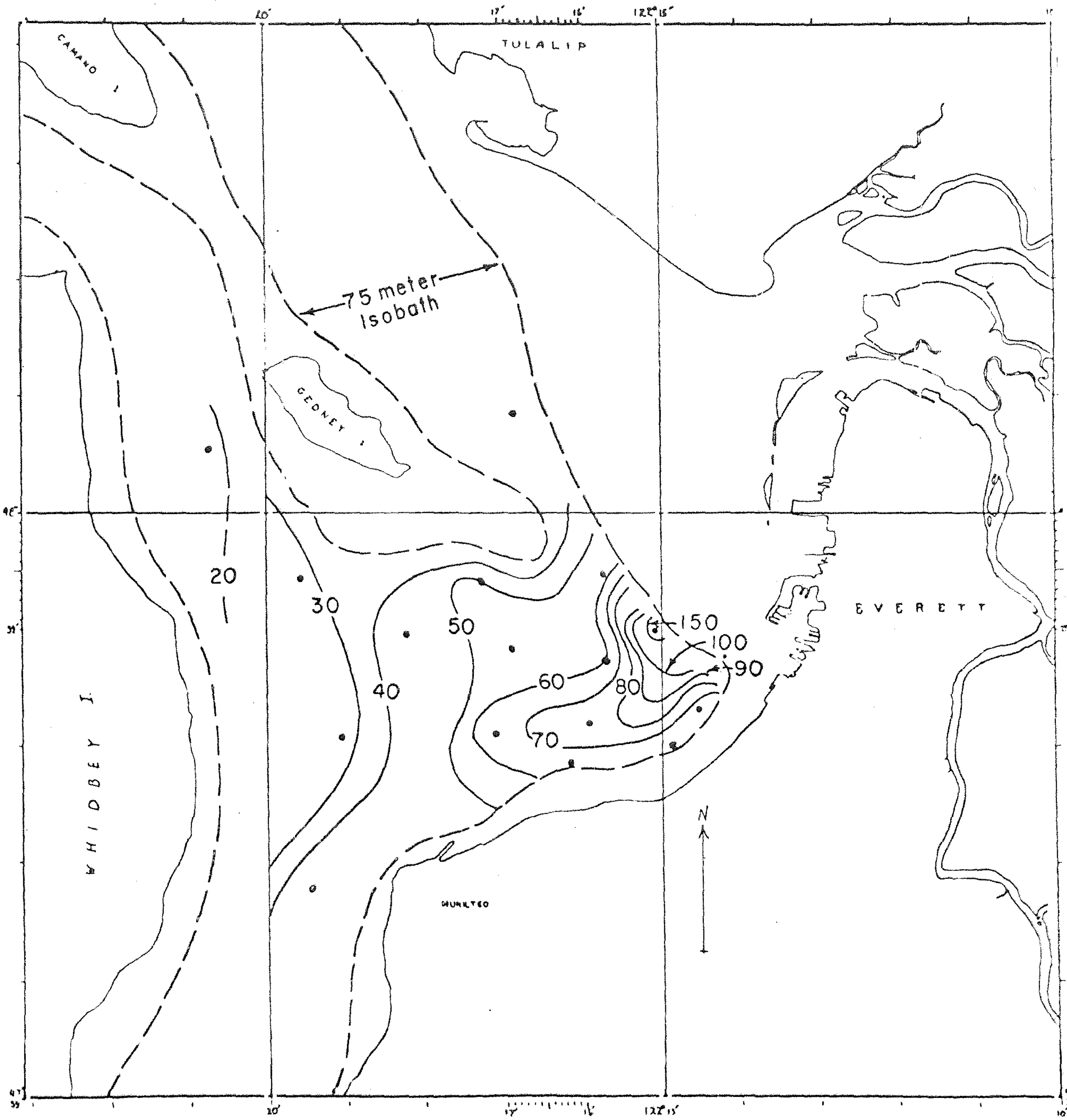

FIGURE 5. SWL (mg/l) at 75 meters, August 1962.

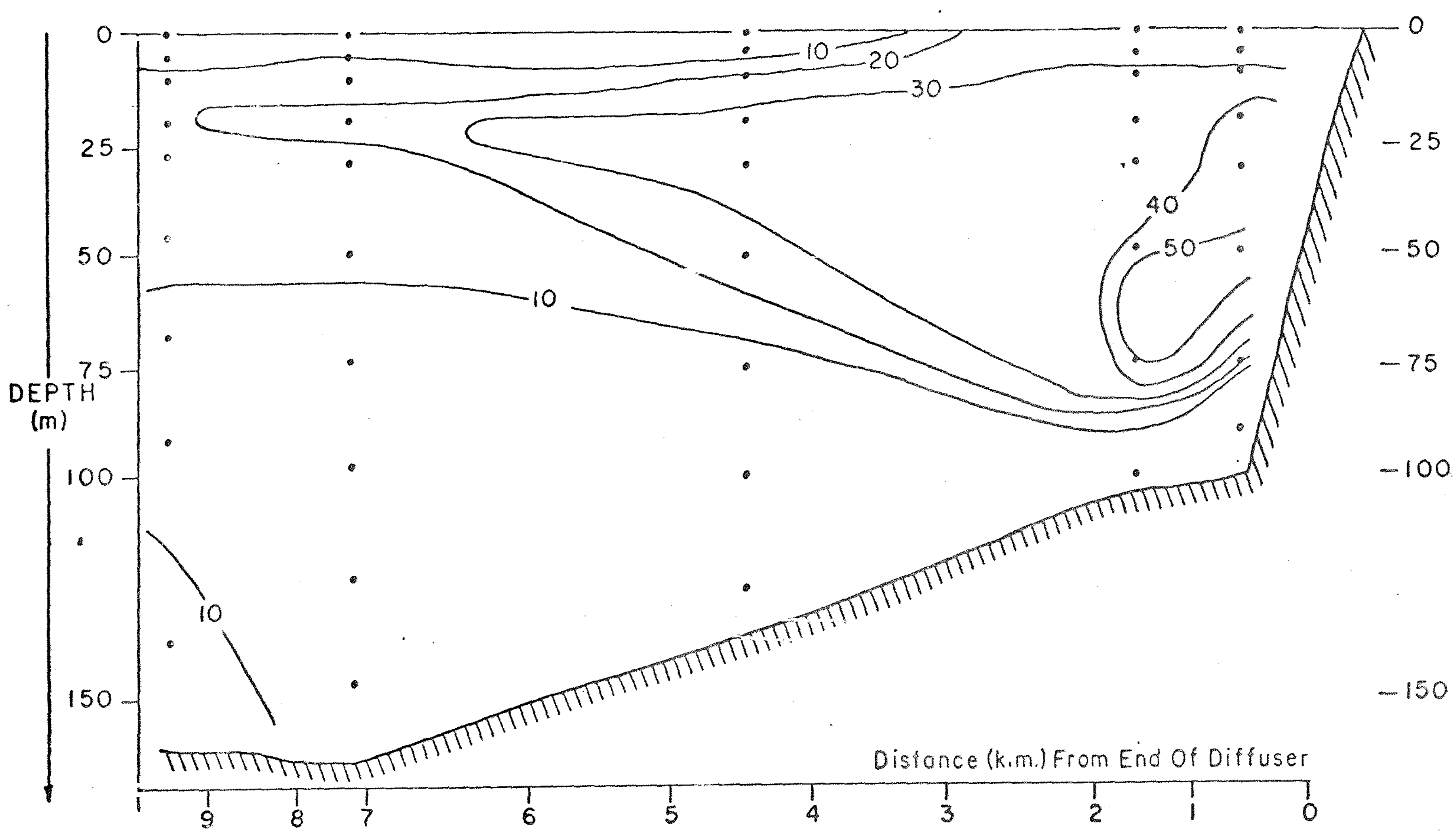

FIGURE 6. Vertical section of SWL (mg/1), February 1963. Pipeline to Saratoga Passage

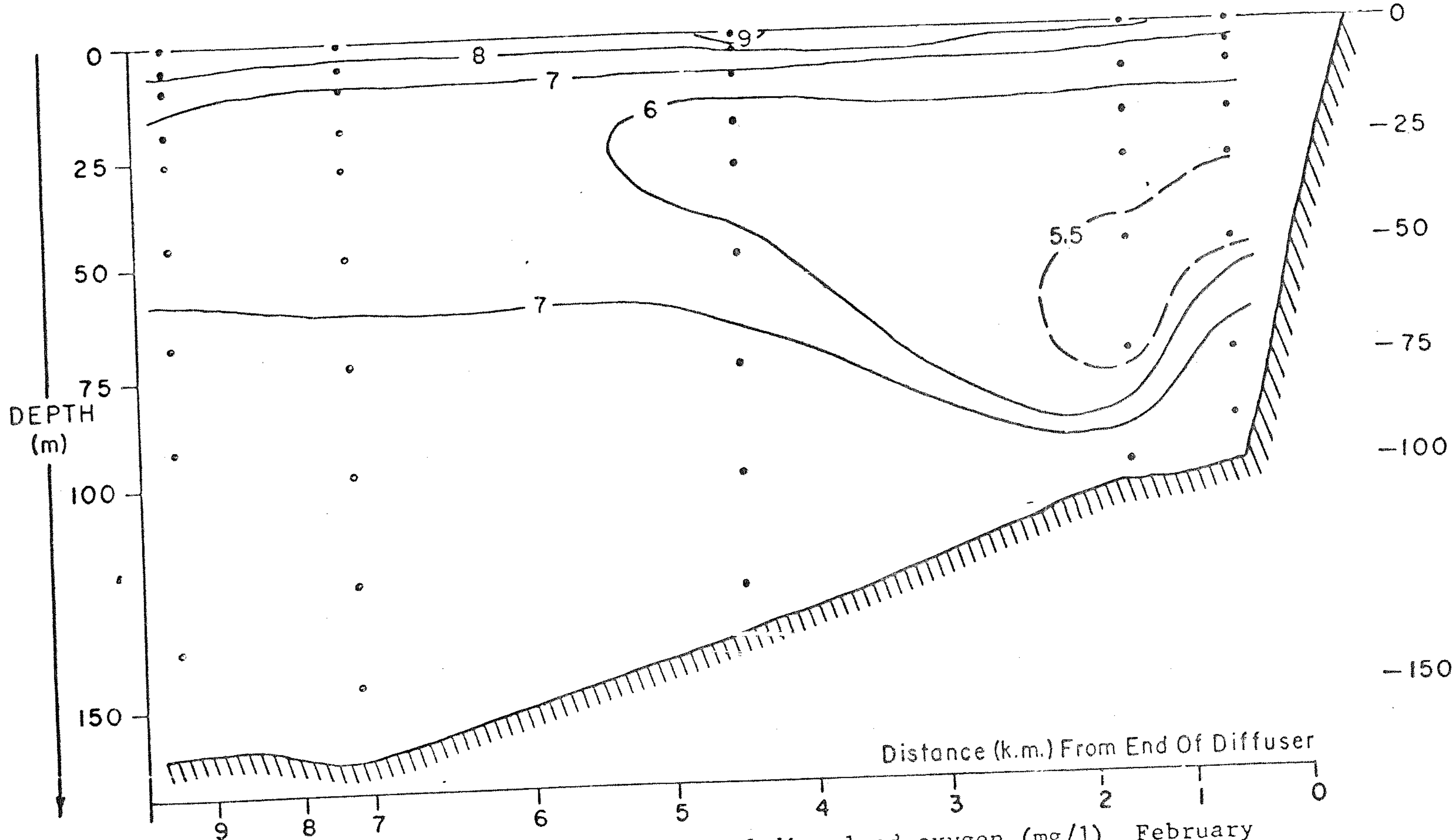

FIGURE 7. Vertical section of dissolved oxygen (mg/1), February 1963. Pipeline to Saratoga Passage.

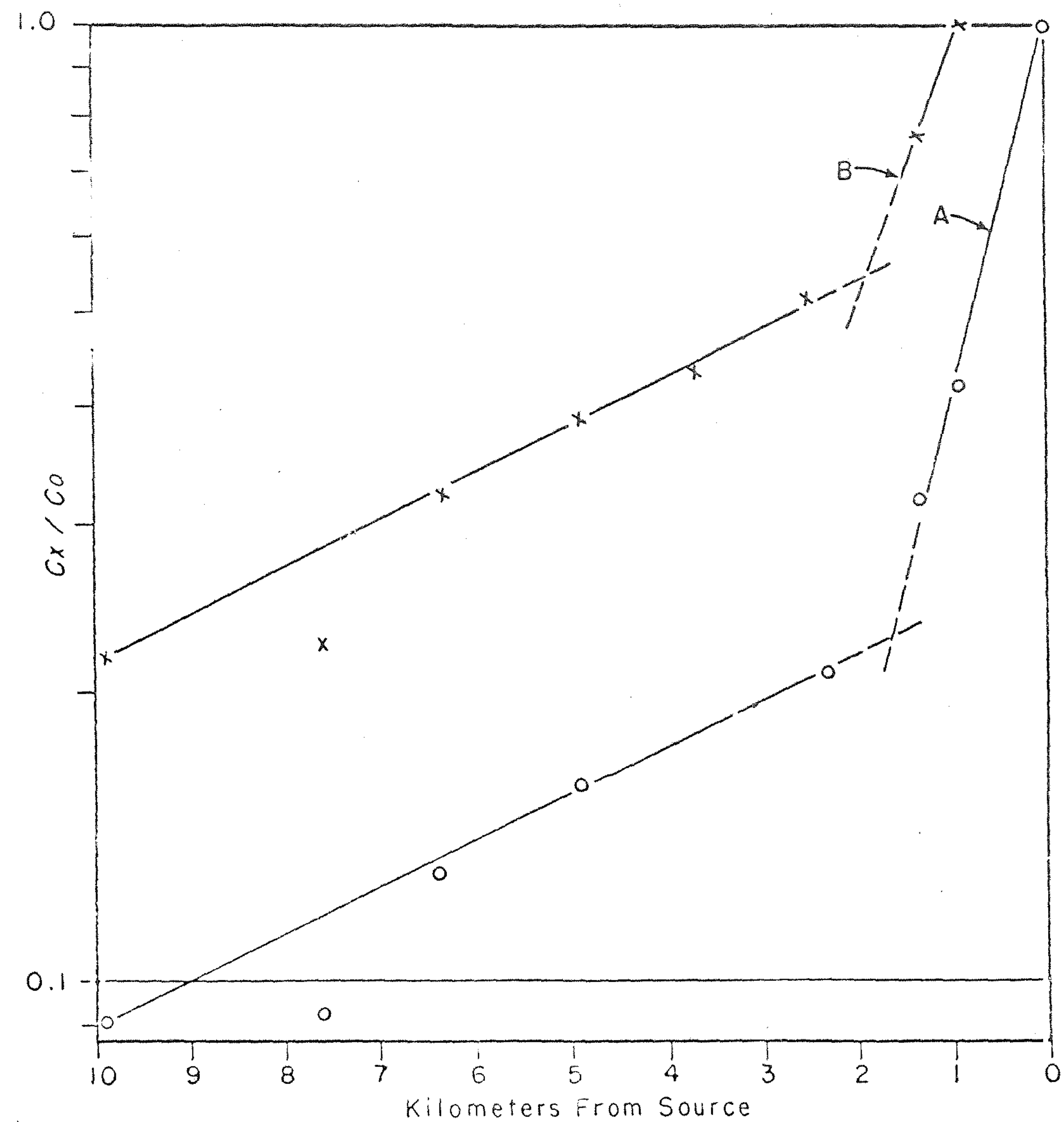

FIGURE 9. Ratio of averaged SWL concentration in core versus distance from source. See text.

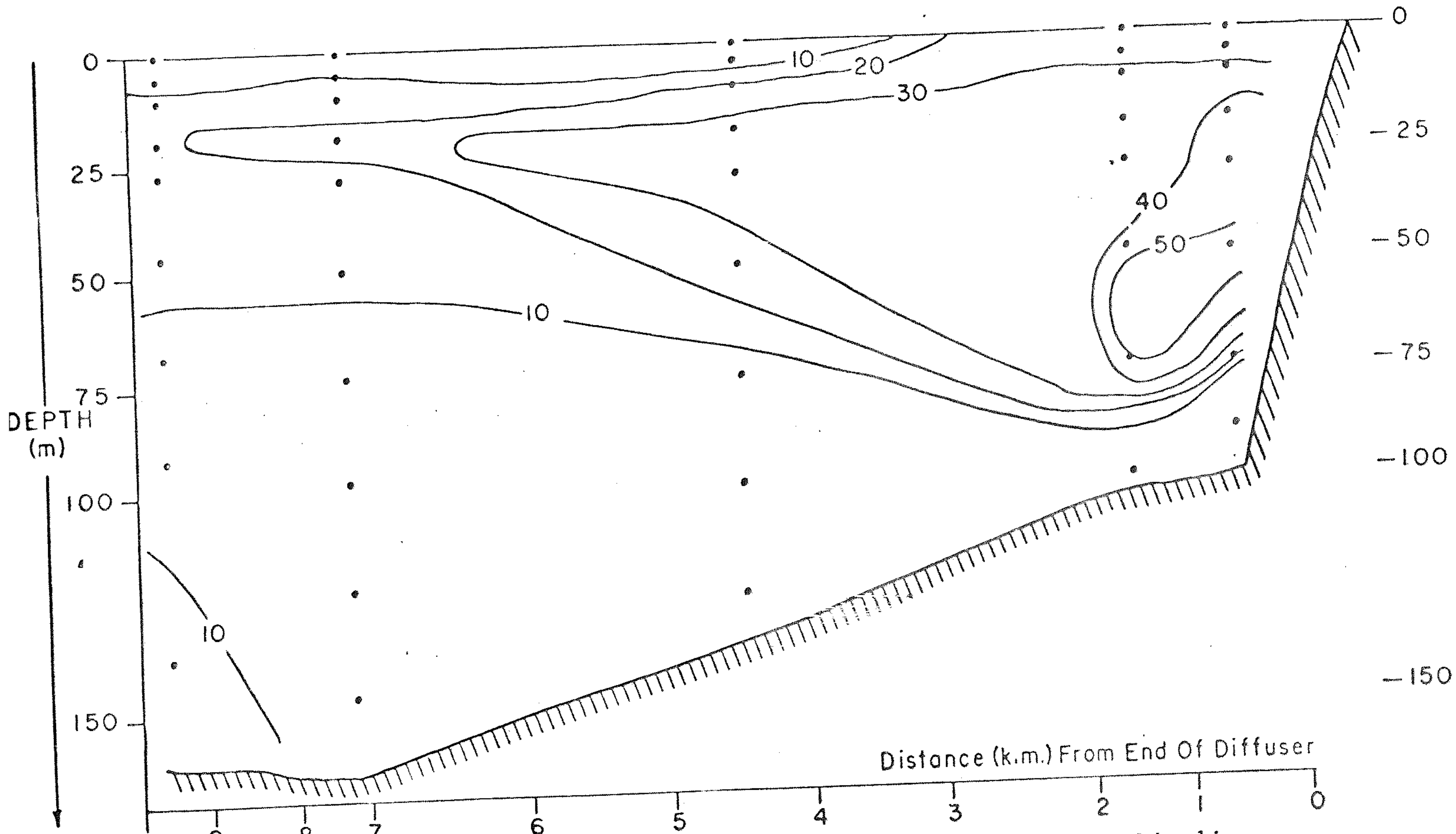

FIGURE 6. Vertical section of SWL (mg/1), February 1963. Pipeline to Saratoga Passage